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AvSP Terrain Modeling and Visualization Tool Survey

TA RFC012 - Final Report

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RFC-012 AvSP Terrain Modeling and Visualization Tools Survey

Introduction

This document was developed for the Aviation Safety Program at NASA Langley Research Center. A need was identified to evaluate the multitude of tools available, including Commercial-Off-The-Shelf (COTS), Government-Off-The-Shelf (GOTS), and Open Source products, to determine the most appropriate set of tools to meet the needs of AvSP for Synthetic Vision Systems (SVS).

We first examine the workflow for developing SVS projects. Six distinct phases are identified. From beginning to end these are: Project Planning, Data Selection, Data Preparation, Geospatial Model Generation, Runtime Applications, and Life Cycle Support. We then identify tools, data, and their sources to meet the requirements of each phase.

To determine the usefulness and quality of these products a survey was presented to the visual simulation developer and user community. 105 people responded to the Request For Participation and 71 people completed at least some portion of the survey. We asked respondents to identify their primary areas of interest in the project development cycle and describe their roles in each phase, provide basic descriptions of their typical projects and the approach used to meet their requirements. We then asked their opinions of a variety of products used within each phase, also providing areas for adding products we didn't previously identify. The results of the survey are provided as a searchable database and published to the survey respondents.

Hands-on examination of several tools was also performed to compare current AvSP SVS practices with alternate approaches. Using a results-oriented approach, we identify SVS project requirements and develop a hierarchy of tools, data and processes that meet those requirements.

Scope

This document touches upon all layers of the SVS project development cycle. The primary focus is to provide an overview of the numerous tools and techniques available to support synthetic vision applications within AvSP.

It also intends to provide planners with a framework for project design. The framework can be implemented by analyzing the research goals to determine appropriate data selection and processing methodologies to meet those goals.

Terms and Definitions

AvSP: Aviation Safety Program

CAD: Computer Aided Design

Clipmapping: a technique of image texture handling that allows the visual simulation application to use extremely large (2^{32} by 2^{32} pixel) texture map datasets. www.sgi.com/software/performer/presentations/clipmap_intro.pdf

DEM: Generic term for Digital Elevation Model data. It is also the name for the terrain data distributed by USGS.

DIS: Distributed Interactive Simulation

DMSO: Defense Modeling and Simulation Office. www.dmso.mil

DTED: Digital Elevation Terrain Data. DTED is a format of terrain data produced and distributed by NIMA. It is available in several resolutions, though most of the resolutions are classified as either “Limited Distribution” or “Secret.” DTED0 is 30 arcsecond resolution (approximately 1 kilometer resolution) and is freely available. DTED1 is 3 arcsecond resolution (approximately 90 meter).

FME: Feature Manipulation Environment, a product of Safe Software, Inc. Performs sophisticated translation of vector data product formats and map projection transforms. www.safe.com

GeoTIFF: TIFF image format with geographic information extension. www.geotiff.org

GIS: Geographic Information System

GPC: Graphics Performance Characterization Group, a branch of the SPEC focusing on computer graphics systems.

HLA: High Level Architecture, a standard developed by the Department of Defense to enable interaction between different types of distributed simulation systems. HLA is the successor to DIS. https://www.dmso.mil/public/transition/hla

LOD: Level Of Detail. A mechanism for reducing the number of polygons rendered per frame by using lower resolution models at distances far from the viewer position.

Mipmapping: The process in which a set of filtered texture maps of decreasing resolution are generated from a single high resolution texture and used to improve accuracy during texture mapping.

MPI: Multigen-Paradigm, Inc. www.multigen-paradigm.com

NIMA: National Imagery and Mapping Agency. www.nima.mil

OpenFlight: A 3D model file format developed by Multigen-Paradigm, Inc. OpenFlight is a de facto industry standard for 3D models for realtime visual simulation applications. (http://www.multigen-paradigm.com/support/dc_standards.shtml)

RTCA: The Radio Technical Commission for Aeronautics. www.rtca.org

SGI: previously known as Silicon Graphics, Inc. www.sgi.com. A developer of high-end computer-graphics workstations and servers.

SISO: Simulation Interoperability Standards Organization, www.sisostds.org. SISO is an organization that defines communication standards for networked simulation systems. SISO manages and maintains the DIS and HLA standards.

SPEC: The Standard Performance Evaluation Corp. This is an independent industry group with the goal of providing objective measurement tools for computing hardware. www.specbench.org

SVS: Synthetic Vision Systems

TEC: Topographic Engineering Center, see USATEC.

Terrain Paging: A type of virtual memory management used in visual simulation applications. Terrain paging allows runtime applications to use terrain models and textures that exceed the physical memory limits of the host computer.

TerraPage: A 3D terrain model format developed by Terrain Experts, Inc. (Terrex). It is optimized to support terrain paging and eliminate cracks between adjacent tiles. www.terrex.com/www/netpages/technology/terra_sub_page.htm

TerreX: Terrain Experts, Inc., makers of TerraVista terrain modeling tools. www.terrex.com

TIFF: Tagged Image File Format. Unofficial home page: http://home.earthlink.net/~ritter/tiff

UML: Unified Markup Language

USATEC: U.S. Army Topographic Engineering Center. An office of the Army Corps of Engineers. www.tec.army.mil

USGS: United States Geological Survey. www.usgs.gov

VisSim: Visual Simulation

Vmap: Vector Smart Map. A NIMA standard for vector map products.

VPF: Vector Product Format. The fundamental format for all NIMA vector map data.

Win2K: Microsoft Windows 2000 Professional, a computer operating system

Inputs and metrics

Information Resources

We considered a variety of factors in developing this report. A hands-on evaluation of a variety of data processing tools and runtime application development environments was principal among them. Of course, we were unable to personally examine all the tools available to support AvSP activities. We also received product reviews through participation in our own survey and through other government-sponsored surveys. NIMA has conducted an annual review, entitled Pathfinder, of COTS and GOTS tools to support its mission.

> The Pathfinder process identifies and assesses tools and technologies to support the mission of the National Imagery and Mapping Agency (NIMA) to provide relevant and timely imagery, imagery intelligence, and geospatial products and services to consumers. Key to the Pathfinder process is the interactive partnership between government subject matter experts, and vendors and developers.
>
> Pathfinder recognizes the strong need to better use increasing amounts of imagery to serve a demanding and expanding customer population, and strives to improve the capabilities of analysts and other users of the Geospatial Information Infrastructure (GII) and the United States Imagery and Geospatial Systems (USIGS).[1]

Many aspects of this mission statement correspond to requirements of AvSP research. The Pathfinder reports have provided a wealth of information supporting this document.

Another survey of terrain visualization tools is performed by U.S. Army Topographic Engineering Center[2]. This survey is intended to identify all the tools available to support battlefield visualization. It does not, however, provide an analysis of the functionality of these tools.

AvSP Workflow

The first step in this task is an examination of existing processes and practices for SVS project development. We identify the phases of project development and identify tools used to support each phase. We then compare current practices with other methods, including COTS and GOTS tools. AvSP has many unique functional requirements, in terms of both data accuracy and runtime performance, which must be considered in the system analysis. We must give careful consideration to these requirements to insure the validity of the SVS product.

Items of particular importance for SVS

- Source data accuracy
    - Maintaining accuracy throughout modeling process

[1] NIMA Pathfinder website. http://www2.nima.mil/pathfinder/tech.html

[2] USATEC Survey Of Terrain Visualization Software website. http://www.tec.army.mil/TD/tvd/survey/index.html

  - Identify and mitigate sources of accuracy loss
- Data distribution rights
  - Licensing and classification issues
- Large area modeling
  - Typical experiment database covers at least 10,000 square miles
- High fidelity model insert
  - Airport models good enough to land on
  - Automatic generation from validated sources
- Runtime applications
  - PC Workstation level platform
  - Limited display size
  - Programmable overlay symbology

Project Planning

The first phase in SVS project development is identifying the research goals and the hardware, software, and data required to meet those goals. A series of questions can be designed to aid in clarifying the requirements for each phase of the project. (See Appendix A - Project Planning Questionnaire) Detailed answers to these questions early in the project design can improve the reliability of development timelines and cost estimates. The questionnaire can also aid in setting requirements for data specification and procurement, data processing validation, and runtime performance constraints.

Many methods are available to assist in formalizing the project planning phase. These range from the Extreme Programming (XP) model of group brainstorming sessions with ideas going on index cards, sticky notes, and whiteboards to rigorous project design and progress tracking tools such as Microsoft Project or Rational Suite AnalystStudio. Each method has strengths and weaknesses that must be measured against the ability or willingness of all parties involved to participate in the day-to-day administration of the project.

The project design approach that seems to best suit management style observed in the AvSP research team is Use Case Design. In Use Case design we build a project specification by defining how the product will work, how the users will interact with it, and what results should be anticipated. Use Case Design describes systems at a high level, defining how components are used but not specifying methods for implementation. Use Case Design is a key component of the Unified Modeling Language (UML) and can be used with any project management system that supports that standard. The Rational Suite is the best example.

Of course, no single method is appropriate for all instances or teams. Therefore we must remain flexible in our approaches to system design.

Survey responses

The grading (across the top of the table) 1=poor, hard to 5=excellent, easy. The numbers in the cells indicate how many responses of that grade were given to the product. Table 1 shows the color spectrum for the vote counts that follow. The survey results for Project Planning Tools are given in Table 2.

0	1	2	3	4	5	6	7	8	9	>=10
Items highlighted in this color were suggested by one or more survey respondents, therefore the vote count may not reflect total usage.										

•Table 1: Vote Count Color Spectrum

	Features					Usability					Learning Curve					Training & Documentation					Customer & Technical Support				
1=poor, hard 5=excellent, easy	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
In-House Development	0	0	1	1	0	0	0	0	1	1	0	0	1	0	1	0	0	1	0	0	0	0	0	0	0
Paper Checklist	5	7	9	3	6	2	3	11	6	8	3	0	2	7	17	3	3	6	5	9	5	4	6	0	6
Spreadsheet	2	3	17	14	5	1	5	13	12	9	0	7	7	15	11	2	7	7	9	9	4	7	10	4	5
ESRI ArcGIS	0	0	0	1	0	0	0	1	0	0	0	0	1	0	0	0	1	0	0	0	0	1	0	0	0
ESRI ArcInfo	0	0	0	0	1	1	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	1	0
ESRI ArcView	0	0	1	0	0	0	1	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0	0
Erdas Imagine	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	1	0
Microsoft Project	0	0	0	5	4	0	0	4	5	0	0	3	4	2	0	0	0	3	4	1	0	1	2	2	2
Microsoft Visio	0	6	1	4	2	0	6	2	3	2	0	3	5	2	3	1	2	4	4	0	1	3	1	2	1
Microsoft Office	0	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0
Microsoft Word	0	1	1	0	0	0	1	0	1	0	0	0	2	0	0	1	0	1	0	0	1	0	0	0	0
Microsoft PowerPoint	0	0	1	0	0	0	0	0	0	1	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0
Objecteering UML	0	0	0	1	0	0	0	0	1	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0
PCI Geomantics EASI/PACE	0	0	0	1	0	0	0	0	1	0	0	0	1	0	0	0	0	1	0	0	0	1	0	0	0
Rapid Imaging Software, LandForm C3	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1
Rapid Imaging Software, VisualFlight	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1
Rational RequisitePro	1	0	1	0	0	0	1	1	0	0	0	1	1	0	0	0	0	2	0	0	1	0	1	0	0
TerraSim TerraTools	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	1

•Table 2: Survey Responses - Project Planning Tools

Data Selection

There are two aspects of the data selection phase that must be examined. We must look not only at data necessary for the SVS application, but also the process used to determine the most appropriate data. There is a broad variety of spatial data available that can support SVS activities, but there are surprisingly few rigorous methods to help ensure that the user chooses the right data. NIMA made an attempt to deliver standard data products for various VisSim tasks. Feature Foundation Data (FFD) provide the basic data to begin a visualization task based on the user's description of the project goals. The FFD is then supplemented with additional data to complete the specific project requirements. However, FFD is not widely available to users outside the DoD.

The lack of data selection standards is reflected in the wide range of responses to the survey questions. The survey respondents expressed a variety of approaches to their data selection processes.

A primary theme was the strong reliance on institutional knowledge and previous experience. This is not surprising, as the respondents are generally seasoned professionals who have worked in the field for several years. They and their organizations have completed similar projects in the past, and they will use those successes to guide their future work. A drawback to this is the possible blindness, or resistance, to new ideas regarding data requirements and specifications. Institutional knowledge must, therefore, be questioned regularly to insure that new concepts can be considered.

With respect to data resolution, the responses range from "the highest-resolution source data available" to "the lowest resolution that supports the need". There is general agreement that data resolution must be limited by the desired runtime framerate, but because of the range of rendering platforms, the appropriate resolution varies greatly from project to project. A few responses expressed a requirement for high resolution data only in specific parts of the database. There was a single reference to the DO-276 / ED-98 standard for aerodrome model fidelity.

As expected, the data resolution requirements also vary according to database usage. High altitude flight simulators require less terrain fidelity than ground vehicle or urban warfare simulations. A key requirement for ground-based simulators and sensor simulation is correlation between the multiple data sources needed to construct the terrain model.

Importance of multi-source databases in simulation activities					
1=Unimportant, 5=Very Important	1	2	3	4	5
Multiple image resolutions	3	2	5	9	19
Multispectral Images	2	1	3	5	14
Visible	1	0	5	5	31
Infrared	3	1	9	2	20
Thermal	3	2	6	5	11
Radar	2	3	12	2	11
Lidar	2	4	8	2	6
Other	2	0	0	1	3
Multiple DEM resolutions	1	0	8	7	19
Multiple LODs in final product	0	0	8	12	24

• Table 3: Survey Results - Importance of multi-source databases

Factors guiding for data selection					
1=Unimportant, 5=Very Important	1	2	3	4	5
Cost	1	3	15	11	16
Distribution Rights	4	3	11	8	15
Product Licensing	3	4	14	6	10
Product Classification	4	2	12	9	7
Availability	0	0	7	14	29
Timeliness	0	2	11	16	20
Area Coverage	1	2	5	14	27
Spatial Resolution	1	4	7	10	27
Spectral Range	7	7	4	10	11

• Table 4: Survey Results - Factors guiding data selection

Supplier	DEM					Stereo Imagery					Aerial Photo					Satellite Imagery					Texture Library					GIS Data					Model Library				
1=poor 5=excellent	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
NIMA	1	2	9	7	8	0	1	2	1	0	0	3	6	3	2	1	1	5	8	3	2	2	1	1	2	2	2	6	6	4	4	2	4	0	3
USGS	0	2	6	10	6	1	2	0	1	1	0	1	9	5	3	0	2	5	3	1	2	2	2	1	1	1	3	4	6	3	4	2	1	0	2
NASA	1	0	2	2	0	0	1	2	1	0	0	0	2	3	1	1	0	2	2	3	0	2	0	0	1	0	0	2	0	1	1	1	0	0	1
NOAA	0	0	3	3	1	0	1	0	0	1	1	1	3	0	3	0	0	1	0	2	0	1	1	0	2	0	0	3	0	2	1	1	0	1	2
US Census	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0
US Coast Guard	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
SPOT Image	1	1	0	3	0	1	0	2	1	0	0	0	1	1	1	1	1	7	5	1	0	0	1	1	0	0	1	0	0	0	0	0	0	1	0
DigitalGlobe	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Space Imaging	1	0	2	1	0	1	0	0	2	1	1	0	0	1	1	1	1	5	4	3	1	0	1	0	0	1	2	1	0	0	1	1	0	0	0
IRS	1	0	1	1	1	1	0	1	1	0	1	0	0	0	1	2	1	2	4	1	1	0	2	0	0	1	0	0	1	0	1	1	0	0	0
RadarSat	1	0	0	0	1	1	0	0	0	0	1	0	0	0	0	3	0	1	1	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0
Canada Landsat	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TerraServer	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Local Govt GIS	0	1	0	1	1	0	0	0	0	1	0	0	0	0	3	0	0	0	0	0	1	0	0	0	0	0	0	0	0	3	1	0	0	0	0
Landisor	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Jeppesen	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Aerial Survey Contractor	0	0	0	0	2	0	0	0	0	1	0	0	0	0	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0
Leica ADS40	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vexcel	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Customer Furnished GPS Data	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ImageLinks	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Topozone	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
Hardcopy Maps	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0
CGSD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
MapQuest	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Object Raku, SextantVWT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

• Table 5: Survey Results - Grading data suppliers

Data Preparation

Having selected the appropriate data for the project, the next step is getting it ready for input into the 3D terrain model generation software. According to the survey results, and our own experience, the principle data preparation tasks for VisSim applications involve format translations and map projection changes. As the complexity of the visualization task increases, it becomes less likely that all the required data will be available in the proper formats for modeling. The newest generation of terrain modeling software, including Creator Terrain Studio and TerraVista, reduce the amount of preparation work required. These new releases have increased the number of understood input data formats and handle more of the map projection processing internally during the terrain build process, but there are still far more data types available than any modeler can read, so some translation work is almost always required. In fact, though the capability of the modeling software is increasing, it is often more efficient to use data processing tools that are optimized for the task even if it adds another step to the project workflow.

Data cleanup is also handled in the preparation phase. For instance, we must verify that the DEM is free of holes and null values. We also check the texture imagery to avoid jarring inconsistencies and anomalies in the source images. Vector data from GIS and CAD packages usually require significant work to prepare them for the terrain modeler.

Identifying possible error sources, minimizing their impact, and tracking their effects is critically important in SVS applications. More so here than in most other VisSim tasks because the end user will rely on the SVS display to perform mission critical functions. Therefore, the data preparation software should report the error or uncertainty introduced at each step of the process.

The fundamental tasks of format translation and map projection are easily understood and can usually be scripted to handle repetitive operations. However, the software used to perform the data preparation tasks is generally quite sophisticated and may require years of experience to exploit its full functionality. Therefore, many organizations choose to contract portions of the data processing work out to specialty service providers. These companies maintain a staff of skilled professionals with the experience to effectively handle the more complex data processing tasks.

Amount of work contracted out	to Data Vendors					to Service Providers					to In-House Data Processing Groups					to other				
1=none, 5=all	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Geographic Projection	7	1	3	1	7	5	2	0	2	6	5	3	2	3	11	1	0	0	1	2
Ortho-correction	7	1	1	3	6	5	2	1	2	6	6	3	3	1	7	0	1	0	0	2
Multi-scene Mosaic	7	0	0	2	4	7	1	1	1	4	5	2	3	1	9	0	0	0	0	1
Multi-resolution Merge	6	0	0	2	3	5	1	2	0	2	4	2	0	2	13	0	1	0	0	1
DEM generation	5	0	0	2	12	6	1	3	2	4	7	2	3	2	6	2	0	0	0	2
Surface Material Classification	7	0	1	1	7	5	1	2	1	5	5	0	3	1	6	1	0	0	0	1
GIS Coverage generation	7	0	0	0	7	6	0	4	1	3	5	0	5	2	13	1	0	0	0	2

• Table 6: Survey Results - Amount of data preparation work contracted out

	Features					Source Data Types					Large Area Processing					Usability					Learning Curve					Training and Documentation					Customer and Technical Support				
1=poor, hard 5=excellent, easy	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
InHouse Database	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
InHouse Tools	0	0	0	0	2	0	0	0	0	1	0	0	0	0	2	0	0	0	0	2	0	0	0	0	2	0	0	0	0	1	0	0	0	0	2
Adobe, Photoshop	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0	0	0	0	1
Autometric, SoftPlotter	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BAE Systems, SOCET SET	0	1	0	2	2	0	0	0	4	1	0	0	2	2	1	0	2	1	1	1	2	2	1	0	1	0	2	0	2	0	1	0	2	0	1
BAE Systems, SOCETSim	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Bentley, MicroStation	0	0	0	2	0	2	0	0	0	0	1	0	0	1	0	2	0	0	0	0	0	1	0	1	0	2	0	0	0	0	0	0	1	1	0
Earth Resource Mapping, ER Mapper	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	1	0	0	0
Erdas, Imagine	0	2	3	7	6	1	0	3	10	4	0	4	4	7	4	1	3	5	5	5	3	2	5	4	4	0	2	8	2	4	1	2	6	3	3
ESRI, ArcGIS	0	1	4	10	6	0	0	5	9	7	2	3	5	5	6	2	1	5	9	4	2	4	6	6	3	1	1	8	6	4	1	3	8	5	3
ESRI, ArcView	0	0	1	1	0	0	0	0	1	1	0	0	1	1	0	0	0	0	2	0	1	0	0	1	0	0	0	1	0	1	0	0	2	0	1
ESRI, MapObjects	0	0	1	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	1	0	0	1	0	1
GRASS	0	1	0	1	0	0	1	0	0	0	1	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	1	0	0	0	1	0	0	0	0
Intergraph, GeoMedia	0	0	0	2	0	0	0	1	0	1	0	0	0	1	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
LizardTech, Mr. SID	0	1	3	1	1	0	1	1	0	1	0	0	2	0	3	0	1	1	2	1	0	1	1	1	2	0	1	2	0	1	0	0	3	1	0
LocMar Compu-Scene TARGET Database Generator	0	0	0	1	0	0	0	0	1	0	0	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0
Luciad, LuciadMap	0	0	0	0	1	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0
MapInfo	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PCI Geomatics	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	1	0	0	0	0	1	0	0	0	0	0	0	1
Safe Software, FME	0	0	0	1	1	0	0	0	0	3	0	0	0	0	2	0	0	1	1	1	0	0	2	0	1	0	0	2	0	1	0	1	1	0	1

• Table 7: Survey Results - Rating data processing tools

Geospatial Model Generation

In this phase, the various source data is transformed into a polygonal model for the runtime application. All of the critical factors for data preparation (data accuracy, large area processing, supported data formats, etc.) carry forward into the model generation phase. To those we add several more that are specific concerns for 3D modeling and visual simulation. The most important consideration is the trade-off between absolute correspondence to the source data and maintaining desired runtime performance. Most of the constraints in the Model Generation Phase are direct results of the capabilities of the runtime environment.

Hardware Constraints on Modeling

Scene complexity constraints vary widely between VisSim applications. Hardware benchmarks on the runtime platform provide a baseline for determining maximum polygon counts and texture load. But it is important to select benchmarking tools that closely approximate the actual application. The Standard Performance Evaluation Corp. (SPEC) and its Graphics Performance Characterization (GPC) Group publish a set of benchmarking tools that can rate hardware performance on a wide variety of tasks. The SPECviewperf and SPECapc℠ for 3ds max™ benchmarks are the most applicable for SVS applications.

Polygon Load Reduction

After determining the capabilities of the runtime hardware, we can calculate the polygon density and texture map size that will allow the desired framerate. Since the hardware will rarely be able to support the full resolution of the source data we must choose a method to reduce the polygon load on the runtime. While polygon reduction methods are commonplace in VisSim applications, they all result in some loss of correlation with the source data. It is the task of the model generation tools to minimize that loss, or restrict it low priority regions.

A simple way to reduce the number of polygons drawn is through the use of Level Of Detail (LOD) switching. This lowers the polygon load by using lower resolution datasets at distances far from the viewer. A drawback for this method, as far as AvSP applications are concerned, is that the range is always calculated from the viewer position. Since the SVS application always shows a forward looking view, the terrain immediately below the viewer position is rarely in view. This means that the highest resolution terrain is unlikely to be visible until the aircraft is very close to the ground.

Another polygon reduction method lies in the choice of tessellation type. Two primary types available are Polymesh and Triangular Irregular Network (TIN). Polymesh is generally better optimized for rendering speed since it allows the runtime to make more efficient use of the rendering pipeline through the increased use of triangle strip, or T-strip, primitives. However, it forces the rendering of many polygons that could be eliminated if neighboring coplanar triangles were joined. Polymesh surfaces also rapidly lose correlation with the source data as lower resolution LODs are introduced, because they always maintain a regular grid organization. CTS, the latest generation of software from MPI, attempts to address this weakness by introducing an Irregular Polymesh. This keeps the basic grid structure but allows the vertices to shift to find a better fit to the source data. TIN surfaces conform to the source data better at lower resolutions because the triangles are calculated to minimize the distance between the surface and the source data while limiting the number of triangles that make up the surface. The TIN generation parameters explicitly define the amount of error allowed and the desired maximum polygon density.

Texture Management

Texture loading and management is another concern of the runtime application that must be addressed in the model generation phase. The problem here is that the amount of texture memory on the graphics cards is quite limited. Even the current high-end graphics cards have no more than 256MB of onboard texture memory. This is compounded by the limited bandwidth available to move the texture data to the card. The AGP4 bus used on most Intel workstations now is a much faster than earlier technology, but still represents a significant bottleneck. TerraVista increases the texture load speed by allowing compressed imagery to be loaded and used directly by hardware that supports that feature. Currently, however, only DirectX supports compressed textures. OpenGL applications must decompress the images before loading them to the graphics hardware.

Effective texture management allows the runtime application to retrieve the specific pieces of image needed to render the current frame and predict the next images to be needed. This texture paging is a common capability of most VisSim applications. Clipmapping is an improvement on basic texture paging that was introduced by SGI with their Infinite Reality graphics hardware. Clipmapping allows the application to page in the image and lower resolution versions of the image simultaneously and roam over extremely large photo textures. Virtual Texture is MPI's version of clipmapping. Virtual Textures can be built using CTS and are supported on Win2K, IRIX, Linux, and Solaris by their Vega and Vega Prime runtime products.

High Fidelity Model Insets

Also key to the realism of the VisSim application is the incorporation of highly detailed models of important features in the terrain model. These features are often hand modeled, based on photographs or architectural drawings, using tools such as Creator, 3D Studio Max, or Maya. This can be an expensive and time consuming process and the results will depend to a great extent on the skill of the artist. New software from TerraSim, (TerraTools) and BAE Systems, (the SOCET SET family of products) provide tools to automate the generation of high resolution site models. TerraTools rapidly generates 3D models from GIS or CAD vector data and allows a great deal of flexibility in the amount of automation vs. guided construction through the use of its extensive graphical scripting language. SOCET SET aids the construction of various terrain data products from stereo overhead photographs, aerial or satellite.

Correlated Databases

Other aspects of terrain modeling are important for specific VisSim applications. These include orthomaps for simultaneous 2D top-down views of the 3D out-of-the-window view, databases for Semi-Automated Forces (SAF) applications where simulated entities interact in the virtual world using defined behavior models, and correlated databases for sensor models such as radar and infrared. While the AvSP has not needed these capabilities in the past, one can clearly see opportunities to extend SVS into these research areas. One prime example of this is the integration work underway with the Runway Incursion Prevention System (RIPS) program. A key feature of this integration will be the accurate positioning of aircraft and support vehicle traffic in the SVS application. The processing of vehicle position data based on input from remote data feeds is a fundamental feature of Distributed Interactive Simulations (DIS) and there are well defined standards in place for this interaction. Using DIS technology, the airport traffic could be displayed as reported by sensors or simulated by SAF software.

Are these features important to your modeling tasks?	No	Yes
Site specific (hand modeled) cultural features (e.g., specific build models)	7	35
GIS derived cultural features (e.g., roads, rivers, buildings, etc.)	6	35
Site specific natural features (e.g., individual tree placement or geological features)	8	34
Correlated Orthographic Maps	12	28
Correlated databases for SAF simulators	18	20
Correlated databases for Sensor Simulation	17	21

•Table 8: Survey Results - Importance of specific modeling features

Quality Assurance

When asked how Quality assurance is performed on the terrain models, the survey respondents were divided into two groups. The majority of respondents perform a visual examination of the terrain database within their runtime environment. They look for obvious holes or cracks in the terrain skin, and check that know or obvious features are in the correct locations. (i.e., rivers and lakes are in valleys and not on the sides of hills, bridges connect with roads, buildings match their footprint on the imagery, etc.) The flyby check can be done in an ad hoc fashion of randomly traversing the terrain, or in a more systematic manner using predefined flightpaths, altitudes, and speeds.

The second group supplements the visual inspection with a more rigorous check, generally involving a statistical measure of the error between the terrain skin and trusted or validated datasets. These datasets are generally the source terrain data that was used to create the terrain skin. However, they can also include GPS locations of known features, topographic maps, and existing avionics systems.

One respondent also mentioned a pair of applicable documents from the RTCA. DO-178B, *Software Considerations in Airborne Systems and Equipment Certification*, and DO-200A, *Standards for Processing Aeronautical Data*, provide guidance on the data processing and accuracy requirements for certifiable aviation datasets. These documents are available for purchase from the RTCA website (www.rtca.org).

Amount of work contracted out	to Data Vendors					to Service Providers					to In-house data processing groups					to Other				
1=none, 5=all	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Site specific cultural feature models	10	2	0	1	0	8	3	3	2	1	4	1	5	4	11	3	1	0	1	1
Site specific natural feature models	10	1	0	1	0	9	1	3	2	1	4	2	3	3	13	3	1	0	1	1
GIS features	10	0	1	3	1	8	2	4	4	1	5	0	5	4	11	3	0	0	0	1
Orthographic Maps	7	1	0	1	3	6	1	1	1	2	4	0	1	4	7	2	0	0	0	1
Correlated SAF databases	5	0	0	1	0	2	2	2	1	1	1	0	2	4	3	1	0	0	0	1
Sensor Model databases	6	0	0	1	1	3	0	1	1	1	3	0	0	2	4	2	0	1	0	1

•Table 9: Survey Results - Amount of terrain modeling work contracted out

	Features					Source Data Types					Large Area Processing					Usability					Learning Curve					Training and Documentation					Customer and Technical Support				
1=poor, difficult 5=excellent, easy	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Custom In-house tools	0	0	1	1	3	1	0	2	0	1	0	0	1	1	3	0	1	0	2	2	0	0	2	1	2	0	1	0	2	2	0	1	0	1	2
3D Nature, Visual Nature Studi o	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	1
AGI STK	0	0	0	1	1	0	0	2	0	0	0	0	0	2	0	0	1	0	1	0	0	2	0	0	0	0	1	0	1	0	0	0	1	0	1
Alias|Wavefront Maya	0	0	1	3	2	0	2	3	1	0	2	1	1	0	0	0	0	1	5	0	0	3	0	2	1	0	1	3	1	1	0	2	2	1	0
Autometric EDGE	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	1	0	0	0	1	0	0	0	0	0	1	0	0	0
Discreet 3DStudio Max	0	1	1	2	4	2	2	0	1	3	2	1	0	1	2	0	0	3	3	2	0	2	3	2	1	0	0	4	2	2	0	1	1	2	1
E&S RAPIDsite	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E&S EaSiest	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0
E&S EarthScape 3D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ESRI ArcGIS	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	1	0	0	0	0
Erdas Virtual GIS	0	0	0	1	4	0	0	0	1	4	0	0	1	1	3	0	0	1	1	3	0	0	2	1	2	0	0	1	2	2	1	0	1	1	2
Intergraph GMS Terrain	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lockheed Martin Compu-Scene TARGET	0	0	0	1	0	0	0	0	1	0	0	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0
MetaVR WorldPerfect	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
MPI Creator	0	0	2	3	1	1	1	1	1	1	2	1	0	0	1	0	0	4	1	1	2	1	1	2	0	0	1	3	2	0	2	0	1	3	0
MPI Creator Pro	1	0	3	6	2	2	0	5	3	0	4	1	2	1	0	1	1	7	4	0	2	3	6	2	0	0	1	4	4	1	1	0	5	3	1
MPI Terrain Bundle	1	1	4	0	0	1	0	3	2	0	2	0	3	0	0	1	0	4	1	0	1	3	1	1	0	0	0	4	1	0	0	0	3	1	1
MPI Road Tools	0	2	1	1	0	0	0	1	0	0	0	2	0	0	0	1	1	0	1	0	0	0	2	0	0	0	1	0	1	0	1	1	1	0	0
MPI SiteBuilder 3D	0	0	1	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	1	0	0	0	1	0	1
MPI Creator Terrain Studio	0	0	0	1	0	0	0	1	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	1	0	0	0	1	0	0	0	0	1	0	1
My3D ShapeViz	0	0	1	0	1	0	0	0	2	0	0	0	0	1	1	0	0	2	0	0	0	0	2	0	0	1	0	1	0	0	0	0	0	2	0
NewTek LightWave	0	0	0	2	0	0	0	2	0	0	0	1	0	0	0	0	0	0	1	1	0	1	1	0	0	0	0	2	0	0	0	0	1	0	0
Object Raku Sextant VWT	0	0	0	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1
Rapid Imaging Software, VisualFlight	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1
Rapid Imaging Software, LandForm C3	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1
SimAuthor TerrainGen	0	0	1	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	1	0
SoftImage	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0	0	0	0	1	0	0
SIM Rational Reducer	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1	0	0	0	0	1	0	0	0	0
Terrex TerraVista	0	3	3	3	2	1	0	3	2	3	0	1	3	4	2	0	1	5	3	2	3	1	3	3	0	0	3	4	1	1	0	0	3	3	1
Terrex TerraVista Pro	0	2	1	1	1	0	0	1	1	1	0	0	3	1	1	0	0	3	1	1	2	1	1	0	0	0	1	2	0	1	0	0	1	2	1
Terrex DART	1	0	2	1	1	0	0	2	1	1	0	0	1	1	1	0	1	1	1	1	2	1	1	0	0	0	1	2	0	0	0	0	1	2	0
TerraSim TerraTools	0	0	0	1	3	0	1	0	1	2	0	0	0	3	1	0	0	2	1	1	0	2	1	1	0	0	0	1	0	2	0	0	0	1	2

•Table 10: Survey Results - Rating Tools for Model Generation

Runtime Applications

We found the greatest fragmentation of survey responses in identification of the important features for runtime applications. This should be anticipated, since each VisSim project will have unique goals and requirements. Even within AvSP, our CAB and GA programs have subtly different requirements with respect to terrain database fidelity and runtime display systems. With only a few exceptions, nearly every runtime feature averaged either 5 or 4.

This weighting to the high importance shows the impact of the runtime environment on the success of the project.

What runtime features are important?					
1=low importance, 5=high importance	1	2	3	4	5
Overall Visual Quality	0	0	0	1	0
Realtime (60Hz) Frame Rate	0	0	0	0	1
Cross-platform support	8	4	3	8	14
OpenGL	0	0	0	1	0
Programmable Shaders	0	0	0	1	0
Consumer-grade hardware	0	0	0	0	1
Multiple display heads	6	1	7	6	19
Multiple graphics pipes (or cards)	5	0	8	10	16
Image Distortion Correction	0	0	0	0	1
Distributed (network-based) applications	3	1	5	13	16
HLA Compliance	0	0	0	0	1
Entity Avatars	0	0	0	0	1
Entity Kinematics	0	0	0	0	1
Entity Dynamics and Behavior	0	0	0	1	0
Vehicle Control Emulation	0	0	0	0	1
Special Effects / Synthetic Natural Environment	1	3	7	10	20
Weather Effects	3	6	8	8	14
Marine Effects	10	6	7	6	4
Weapons Effects	8	2	4	9	10
Physics-based sensor models	0	0	0	0	1
Dynamic Lights and Shadows	0	0	0	1	2
Flares	0	0	0	1	0
GIS Integration / Interaction	0	0	0	0	1
Database Interoperability	0	0	0	0	1
Standard Data Formats	0	0	0	0	1
GeoTIFF support	0	0	0	0	1
12-bit Texture Support	0	0	0	0	1

• Table 11: Survey Results - Importance of runtime features

The majority of respondents indicated that they, like AvSP, develop their own runtime applications in-house. Usually, third-party graphics libraries are used, increasing the development team productivity and the flexibility of the final product. These libraries range in complexity from simple layers on the OpenGL or DirectX libraries to complete application development frameworks. The product that garnered the most votes in the survey was MPI Vega (16) with CG^2 VTree (7) a distant second. Though many people indicated using these tools, they were generally only rated “Average” in the survey criteria. A possible explanation for this is the very complexity of the problems that they are designed to address.

How are your runtime applications developed?	
Purchase Turn-Key applications	15
Contracted Development	15
In-house Development	33

•Table 12: Survey Results - Runtime Application Development

	Features					Source Data Types					Large Area Processing					Usability					Learning Curve					Training and Documentation					Customer and Technical Support				
1=poor, difficult 5=excellent, easy	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Custom In-house tools	0	0	1	1	1	0	0	0	0	1	0	0	1	0	2	1	0	0	0	2	1	1	0	0	1	0	1	0	1	1	0	0	0	1	1
CATI XIG	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
CG2 Mantis	0	0	1	1	3	0	0	2	2	0	0	0	2	1	2	0	0	1	3	1	0	0	4	1	0	0	0	4	0	0	0	0	2	2	1
CG2 MultiViz	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CG2 Vtree	0	1	1	3	2	1	3	2	1	0	0	1	4	1	0	1	0	2	3	1	1	2	3	1	0	0	2	1	3	1	0	2	2	0	2
DAS Apex	0	0	0	1	1	0	0	1	0	1	0	0	0	1	1	0	0	0	1	1	0	0	1	0	1	0	1	0	0	1	0	0	1	0	1
Erdas VirtualGIS	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1
FlightGear	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gizmo3D	0	0	0	1	1	0	2	0	0	0	1	1	0	0	0	1	0	1	0	0	0	1	1	0	0	0	1	0	1	0	0	2	0	0	0
Lockheed Martin Compu-Scene	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	0	1	0	0	0	0	0	1	0
Luciad LuciadMap	0	0	0	0	1	0	0	0	1	0	0	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0
MaK Stealth	0	0	1	2	1	0	1	0	2	1	0	0	0	3	1	0	0	1	2	1	0	0	2	1	1	0	1	0	2	1	0	1	0	2	1
MetaVR VRSG	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1
MetaVR ChannelSurfer	0	0	1	1	1	0	0	0	2	1	0	0	0	2	1	0	0	1	1	1	0	0	1	1	1	0	1	0	1	1	0	1	0	1	1
Microsoft DirectX	0	0	0	0	1	0	0	1	0	0	0	0	1	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	1	0	0	0	1	0	0
MPI FlightIG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MPI Vega	1	0	6	4	5	1	1	7	2	4	2	2	6	2	2	2	2	8	3	1	2	4	6	2	1	3	4	6	2	0	1	3	6	3	0
MPI Vega Prime	0	0	0	2	1	0	0	1	1	1	0	0	1	1	1	0	0	1	1	1	0	0	1	1	1	0	0	1	1	1	1	0	1	0	1
NPS NPSnet	0	0	1	1	0	0	0	1	0	0	0	0	0	1	0	0	0	1	0	0	0	0	1	0	0	1	0	0	0	0	1	0	0	0	0
OpenGL	0	0	0	1	0	0	0	1	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	1	0
OpenSceneGraph	0	0	2	0	0	0	0	1	1	0	0	1	0	0	0	0	0	2	0	0	0	2	0	0	0	0	1	0	0	0	0	0	0	1	1
OpenSG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Plib	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PTC Division	0	0	1	1	0	0	0	2	0	0	1	0	0	0	1	0	0	0	0	2	0	1	1	0	0	0	1	1	0	0	1	0	0	0	0
Quantum3D OpenGVS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rapid Imaging Software, VisualFlght	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1
Sense8 WorldToolKit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SGI Performer	0	0	2	1	0	0	0	2	1	0	0	0	1	1	0	0	0	2	1	0	0	0	2	1	0	0	0	2	0	1	0	0	1	1	1
SimAuthor FlightViz	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
STRICOM ModStealth	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TGS OpenInventor	0	0	0	1	1	1	0	0	0	0	1	0	0	1	0	0	0	1	0	1	0	0	2	0	0	0	0	0	2	0	0	0	1	0	0
VRML	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

•Table 13: Survey Results - Rating Runtime Applications

Life Cycle Support

Life cycle support is a project management task that ensures the procedures used in the development of the VisSim project are adequate to maintain the integrity of the product.

Included in life cycle support are software update tracking, data maintenance, product delivery and post-delivery support. There are many products available to support the software development life cycle. These tools may also be applied to the terrain database modeling task, but recently tools have been introduced by Multigen-Paradigm, Inc. and NXN Software, Inc. that are designed specifically for the management of the modeling task. These tools provide mechanisms to track data sources and identify the models affected by updates to these sources. Other important information includes the original map projection and resolution, the kind of processing performed on the data, and the error budget for those processing tasks.

Life Cycle Support Information		
	No	Yes
Is revision control needed / provided during model development?	6	29
Are source datasets tracked for changes?	15	19
Are model updates required when new data is available?	11	20
Are distribution packages built for final products?	10	16

• Table 14: Survey Results - Life Cycle Support Information

	Features					Usability					Learning Curve					Training & Documentation					Customer & Technical Support				
1=poor, difficult 5=excellent, easy	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
In-house tools	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0	0	0	1	0	0	0	0	0	1
CAE SIMEX	0	0	0	0	1	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0
CVS	0	0	3	3	2	0	0	3	4	1	0	1	2	5	0	0	2	2	3	0	2	2	1	2	0
Discreet 3ds Max	0	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	0	0	1	0	0	0	1	0	0
L3 Communications SEMS	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0
Lockheed Martin Compu-Scene TARGET	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0
Microsoft SourceSafe	0	0	1	0	0	0	0	1	0	0	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0
MPI Creator Model Studio	0	0	3	1	0	0	0	2	2	0	0	1	3	0	0	0	2	2	0	0	1	0	1	0	0
NXN AlienBrain	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PRCS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rational ClearCase	0	0	4	0	1	0	0	3	1	0	0	0	3	1	0	0	1	3	0	0	0	0	3	1	0
RCS	0	1	1	0	0	0	1	0	1	0	0	0	2	0	0	0	1	1	0	0	1	1	0	0	0
SCCS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
tkcvs	0	0	0	1	0	0	0	0	0	1	0	0	0	1	0	0	0	0	1	0	1	0	0	0	0

• Table 15: Survey Results - Rating Life Cycle Support Tools

AvSP Development Environment

Here we discuss the aspects of Terrain Modeling and Visual Simulation with specific focus on the requirements of the AvSP.

Operating System and Hardware

The AvSP research team has chosen to standardize all work a Win2K environment. All data processing and runtime applications must work on that operating system. This is not a very restrictive requirement, since most of the industry is already supporting that platform. The biggest limitation imposed by the Win2K requirement is on the sophistication of the computer platform. While a typical SGI computer used for VisSim has at a minimum 2 CPUs and can support as many at 512 CPUs and 16 graphics pipelines, the Windows environment does not scale well beyond 2 CPUs and 2 graphics pipelines.

Industry Standards

One of the general AvSP project guidelines is that there be as little as possible tying the research to any specific software or hardware system. Therefore, adherence to industry standards has a high value. Unfortunately, there are few formal standards that support VisSim and we must rely on de facto industry standards. We have identified several file formats that are supported by the majority of VisSim applications.

Geospatial Source Data

For raster data, imagery and terrain data, geoTIFF is a widely used format. It is an extension of the TIFF format and supports the same data types as TIFF, from 1-bit to 16-bit integer and 32- or 64-bit IEEE floating point data, though not all the data types can be read by all processing tools. (For instance, TerraVista version 3.0 needs geoTIFF terrain to be signed 16-bit integer. It does not understand any other data type for geoTIFF terrain. Creator Terrain Studio version 1.0 understands geoTIFF for image texture files, but not for terrain data.) Another aspect of geoTIFF that must be considered is TIFF + TIFF World Files. ESRI developed the world file method to attach geographic information to a variety of graphics file formats. By using the same base name and a modified extension (*.tif and *.tfw or *.jpg and *.jgw, for example) the readers that support this format can read the geographic information from the associated world file. A limitation of this method is that it only supports UTM projection in North American 1983 Datum.

When reviewing vector data standards, such as GIS or CAD data, we found that three formats compete for primacy. ArcShape is the native format of the ArcGIS family of products from ESRI. Many COTS and GOTS GIS tools support ArcShape as an interchange format. Primarily a 2D format, there is also a 3D extension that is supported by some applications. Another commercial format is DXF, which was developed by AutoDesk for their AutoCAD product. CAD formats are generally used for highly detailed construction plans and facilities management data. NIMA has developed VPF as a format to support the activities of the DoD. It forms the basis for the majority of NIMA GIS data products, including VMaps, VITD, and World Vector Shoreline. These products are available at varying levels of classification, depending on data resolution and the geographic region covered.

The USGS developed the Spatial Data Transfer Standard (SDTS)[3] to insure that the data generated and used by various geospatial analysis tools could be shared by all federal government agencies. SDTS incorporates standards for point, vector, and raster data types. In 1998 SDTS was approved as an ANSI standard and its use is now mandated for all federal agencies.

3D terrain models

Large Area Models

Due to the large size of the experiment areas necessary for AvSP research projects, the SVS Runtime applications require pageable polygon or polymesh terrain models and large high-resolution geospecific phototextures. OpenFlight, developed by Multigen-Paradigm, Inc., is the widely acknowledged standard for these 3D model files. All the major terrain modeling applications can import OpenFlight files and most can write in that format. However, OpenFlight is not without limitations. The worst one for SVS applications is the handling of LOD matching between adjacent terrain tiles. Incorrect edge vertex processing leads to anomalies such as "cracks" in the terrain between tiles or significant expenditure of the polygon budget at tile boundaries to eliminate the cracks. This was a severe limitation of MPI's Terrain Pro product. It has been addressed by various means in new software from MPI and TerreX. With Creator Terrain Studio, MPI has introduced a new tool that helps eliminate cracks by modifying the tile edge vertices that, while not really removing the cracks, effectively prevents them from ever being visible in the runtime environment. TerreX has dealt with this problem by introducing a new terrain file format, TerraPage. While similar to OpenFlight in that it is an LOD switched polygonal surface model, it extends the capability with their patented SmartMesh™ technology. SmartMesh™ eliminates cracks by adding separate LODs at the tile edges to handle the edge matching.

Also important for AvSP applications because of the large experiment area is support for round earth (geocentric or geodetic) models. For small areas, less than one degree square, the VisSim applications can safely use a flat-earth model with "up" always along the positive Z axis. However, as the view range and experiment area expands, the flat-earth model exhibits anomalies that must be corrected in the runtime application.

High Fidelity Site Models

We need more sophisticated tools than are available within the large-scale terrain modeling packages if we are to produce an airport model "good enough to land on." Providing the pilot an accurate visual representation of the airport within the SVS display requires either a great deal of hand modeling in Creator (or a similar 3D modeling tool), or a highly detailed source dataset and advanced model generation software.

The kind of source data available defines to tool used to build the model. Hand-modeling the airport is the only alternative if only building photographs and coarse size measures are available. If high-resolution overhead stereo photographs are available, aerial or satellite, use SOCET SET to generate the models. SOCET SET is still a labor-intensive process, but it can produce 3D models and GIS databases as accurate as the source imagery. TerraTools can be used if GIS or CAD data can be provided. TerraTools has a clear advantage if a standard GIS schema is used for multiple airports. It uses a scripting language that makes it possible to write a single script to build any number of airports, as long as their data is provided in a standard format.

[3] USGS SDTS webste. http://mcmcweb.er.usgs.gov/sdts/whatsdts.html

These site models should be delivered in OpenFlight format to ensure that they can be inserted into the overall terrain database.

Software Development

Programming Environment

Runtime applications also have relevant industry standards. Given the mandate of a Win2K target platform, the preeminent software development package is the Microsoft Visual Studio. Visual Studio is an Integrated Development Environment (IDE) that provides the developer a programming editor, compiler, debugging tools, and easy access to all Microsoft programming languages. Visual C++ is a subset of Visual Studio, including only the C++ development tools. But that is adequate for most VisSim software development.

Graphics API

There are two competing standards for graphics programming libraries. OpenGL was originally a proprietary library developed by SGI under the name IrisGL. In 1992 SGI opened the standard and created the OpenGL Architecture Review Board (ARB), which now controls the OpenGL specification. The chief advantage of OpenGL is its broad, multi-platform support. Applications written for OpenGL may be easily ported to any other OpenGL compliant hardware or operating system. OpenGL is a highly flexible and extendable API that is the main choice for developers in the VisSim community. Direct3D is the graphics library developed by Microsoft for its Windows operating systems. Direct3D is a member of the DirectX family of libraries, which also includes Direct3DX (Effects and Textures), DirectInput (supporting input devices such as joysticks and steering wheels), and DirectAudio (music and sound effects). DirectX was created to ease game development for the PC platform, but has made significant inroads in VisSim. DirectX is a highly functional set of APIs, but it is only available for Microsoft Windows platforms.

Scene-Graph Library

While it is possible to create SVS applications by programming with the OpenGL or DirectX APIs directly, it is generally advisable to use higher level APIs built on these lower level libraries. The high level APIs provide support for such critical components as runtime database management, optimized terrain and texture paging, interface with other applications, and special effects and synthetic environment rendering. There are many APIs available, both commercial and open source, but many are designed for specific hardware or are based on closed proprietary systems.

Two commercial scene-graph APIs are VTree from CG^2 and Vega from MPI. Both of these packages have large installed bases and are compatible with the SVS operating environment. VTree has an advantage in terms of usability, since it is a fully object-oriented C++ library that integrates easily into the Visual C++ and MFC environment. However, Vega is a mature product that has much more robust support for geodetic earth models, which is very important for AvSP SVS applications. The newest generation of Vega, called Vega Prime, is available now and as it is an entirely new implementation of their library in C++, it eliminates much of VTree's C++ usability advantage. It also promises cross-platform support not available in Vega (including Microsoft Windows, SGI IRIX, Sun Solaris, and Linux) through the use of a new platform-independent scene-graph engine. However, until Vega Prime is a bit more mature, perhaps until the beginning of CY03, we cannot advise full-scale migration to that platform.

The choice of modeling tool also impacts the available choices of runtime environments. While CG^2 has worked closely with Terrex to ensure that VTree properly handles the

TerraPage file format, they do not have the same relationship with MPI. Therefore, they have no native support for the CTS terrain paging format. Likewise, Vega and Vega Prime are readily able to read the data produced by Creator Terrain Pro and CTS, but cannot read TerraPage databases. Since Terrex and MPI have both published the specifications for their terrain file formats, it would be possible for the AvSP development team to add the read functionality to applications built on either API. However, it would be arduous work and would entail a significant maintenance commitment since the file formats are subject to periodic revision.

An alternative is to use an Open Source scene-graph library that would not be tied to a specific data format. The OpenSceneGraph project (www.openscenegraph.org) has announced support for both TerraPage and OpenFlight terrain formats. This system shows great promise, but until the product matures (the current release is beta version 0.8.45) we cannot recommend migration to that platform.

Summary: AvSP Standards Requirements

- Operating System: Microsoft Windows 2000 Professional
- Computer Hardware: Multi-processor Intel based Workstation
- Graphics Hardware: OpenGL compliant graphics board
- Project Planning
  - Rational AnalystSuite, or
  - Microsoft Project
- Life Cycle Support
  - Rational ClearCase, or
  - Microsoft SourceSafe
  - MPI Creator Model Studio
- Source Data Formats
  - Raster: GeoTIFF, SDTS
  - Vector: ArcShape, SDTS
  - Model Library: OpenFlight
- Data Processing
  - Raster: Imagine (Erdas)
  - Vector: ArcGIS (ESRI), FME (Safe Software)
- 3D Model and Scene-Graph API

- TerraPage (TerreX) and VTree (optionally, + Pro + I-Data) (CG^2), or
- OpenFlight (Creator Terrain Pro, MPI) and Vega + LADBM (optionally, + Symbology + Navigation and Signal Lighting) (MPI), or
- OpenFlight + MetaFlight (Creator Terrain Studio, MPI) and Vega Prime + LADBM (optionally when available, + Symbology + Navigation and Signal Lighting) (MPI)

- Programming Environment: Microsoft Visual C++
- Graphics API: OpenGL

Appendix A - Project Planning Questionnaire

Research Objective

What do you expect to learn from this project? Provide an overview of the experiment. (i.e., develop pilot training methods, test new navigation aid, etc)

Project Timeline and budget

Start, end, and milestones

Include dates and deliverables.

Software development budget

Runtime Database development budget

Source product procurement budget

Travel requirements

Experiment Procedure

How experiment will be performed?

Who are the research subjects?

Research Team Members

Invited Guests

General Public

Other

What is the role of the SVS software in the experiment?

What is the role of the Runtime Database in the experiment?

Experiment Environment

Where will the experiment take place? (In a lab or an aircraft?)

Number and type of displays

Data Input / Output

External sensors

Live

- Simulated
- Recorded

Data server source and update rate

- SCRAMnet
- UDP/TCP Sockets
- RS-232
- USB
- Other

Interface with Distributed applications

- COM
- CORBA
- DIS/HLA
- Other

Data logging requirements (Data Element, Frequency)

Experiment Equipment

Computer and graphics hardware

- Primary
- Secondary
- Backup
- Control workstation

Number and type of displays

- Research
- Control
- Other

System controls and their locations

- Keyboard & Mouse
- Knobs, Dials, & Switches

- Flight controls (joystick, yoke, etc)
- Other

Network

- Data
- Video
- KVM (Keyboard, Video, Mouse) Extenders
- Voice Communication
- Other

Equipment ownership

- Committed 100% to this project
- Shared with other project
- POC for other project

Equipment Status

- Existing equipment
- New Purchase
- On Loan
- Loaning organization
- Authorizing POC

Equipment Standardization

- OS version and patch level
- Graphics card driver version
- 3rd party software / version
- Administering Authority

Software Requirements

Identify modifications to current SVS software

- Display configurations
- Control GUI

- Symbology Overlay
- Software Interfaces
- Sensor Simulations
- Other

Terrain Database Requirements

Experiment target location

Database extent

High Priority Airports

Low Priority Airports

Terrain model accuracy requirements

- Allowable error and range from Airport
- Ground-Truth for validation

Source Data Providers

- DEM
- Imagery
- GIS
- Model Library
- Other

DEM

- Required Resolution
- High resolution inset locations

Geospecific Imagery

- Required Resolution
- High resolution inset locations

Alternative Imagery

- Monochromatic (e.g., HUD Green)

- Elevation-based shading
- Feature Attribute textures

GIS-derived cultural features

- Roads
- Rivers
- Buildings
- Other

Stock 3D models

- Generic buildings / tower models
- Generic terrain textures
- Other

Site-specific 3D models and Reference data

- Complete Airports
- Runways
- Taxiways
- Terminal Buildings
- Identifiable Landmarks
- Other

Correlated databases (i.e., traffic network for RIPS)

- Application
- Database Format